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Accurate Waypoint Navigation using Non-differential GPS

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Discussions

- Project Background
- GPS Deficiencies
- The Kalman Filter
- Position Update Message
- Path Following
- Operator Control Unit
- Summary

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Background
The Robotic System

- The Urban Robot (URBOT) is designed for the Army to perform reconnaissance of tunnels and sewers.
- It returns digital audio/video to its companion Operator Control Unit (OCU), via four cameras and a microphone.
- Its snout contains a high performance digital camera, microphone, and lights. It can tilt +/- 90 degrees.
- It is watertight and invertible.
- The URBOT and the OCU form a network system.

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Background

- The goal was to develop a robust waypoint navigation capability for a small mobile robot
- Intended for use in tactical situations
  - No Differential GPS available

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Selected Sensors

- GPS – NovAtel OEM-4 dual-frequency
- Gryo - Systron-Donnor QRS11 quartz gyro
- Compass - Microstrain 3DM
- Odometer – Hall-effect sensors

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GPS Deficiencies

- Broken into two broad categories
  1. High frequency noise
  2. Long-term drift

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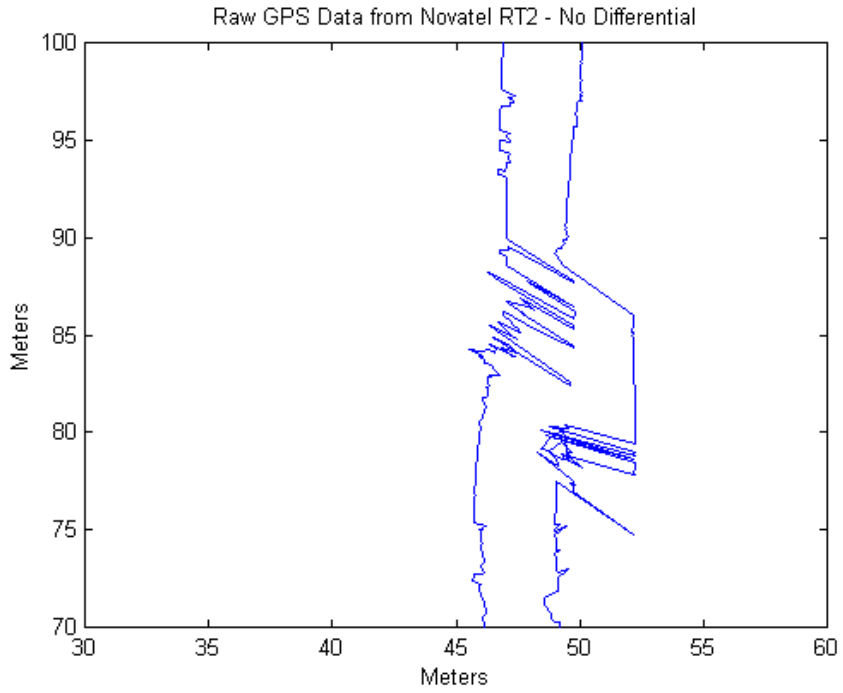
GPS Deficiencies

- High frequency noise
  - Sudden jumps or spikes in the GPS position



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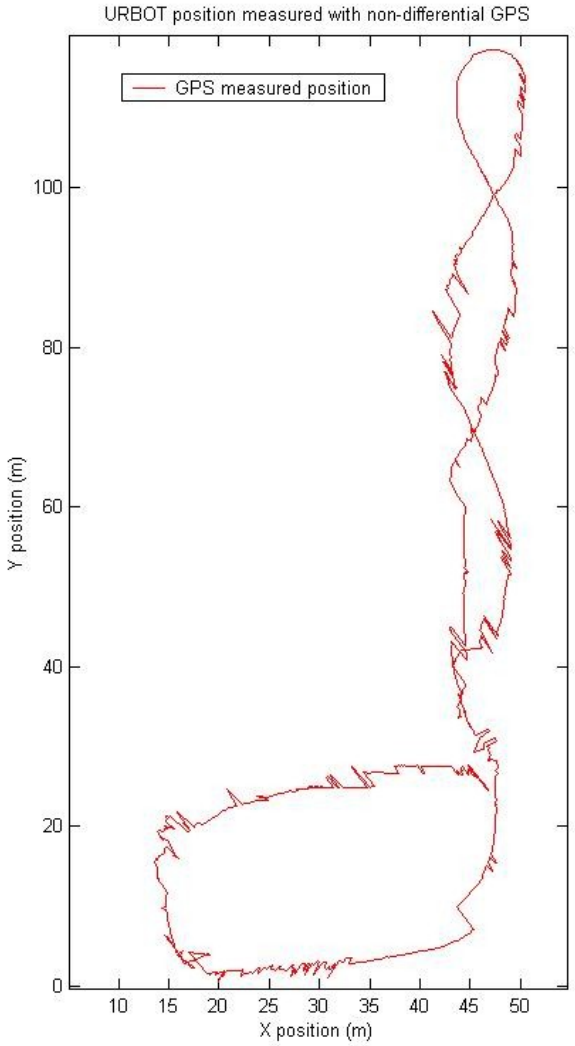
GPS Deficiencies

- High frequency n
- Causes
  - Satellites coming
    and out of view
  - Multi-path effects



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GPS Deficiencies

- Long-term drift
  - Changes in the position that occur over hours instead of seconds
  - Very hard to see on a track plot but easy to see in testing.
- Causes
  - Ionosphere and troposphere effects
  - Satellite geometry

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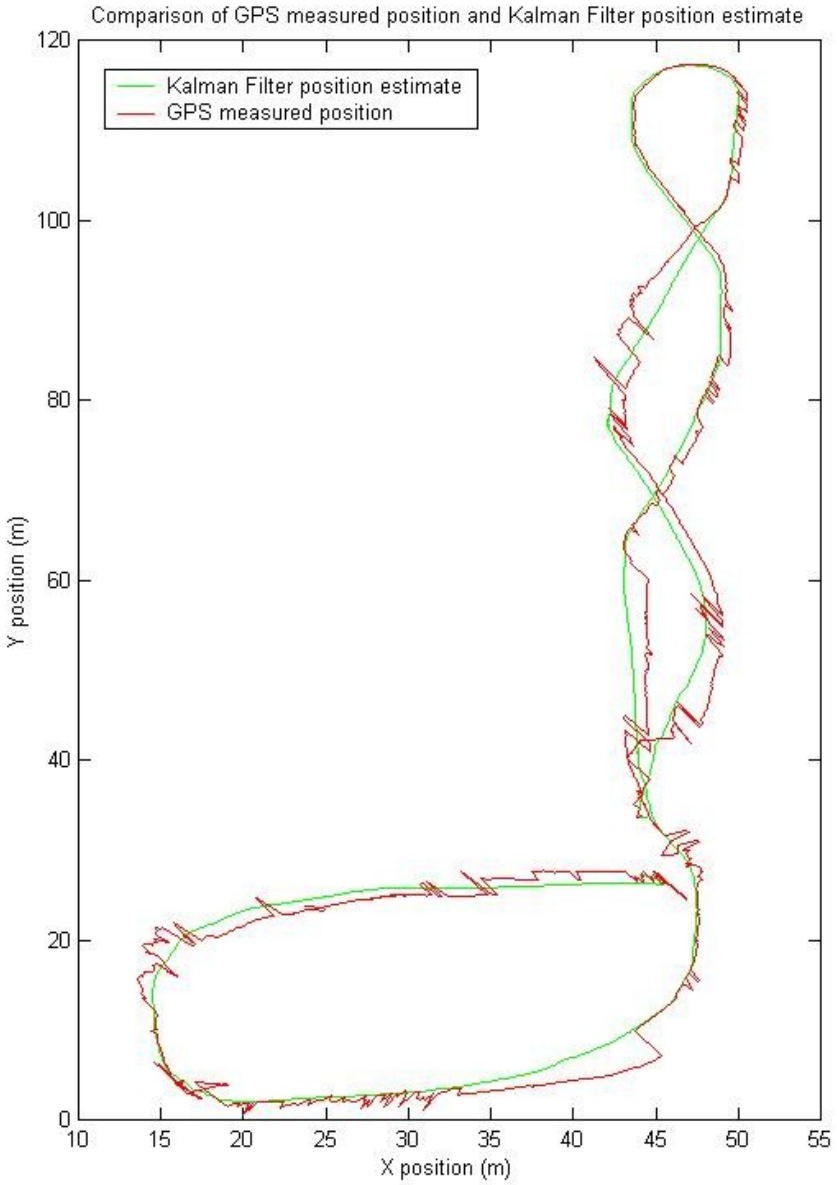
Kalman Filter

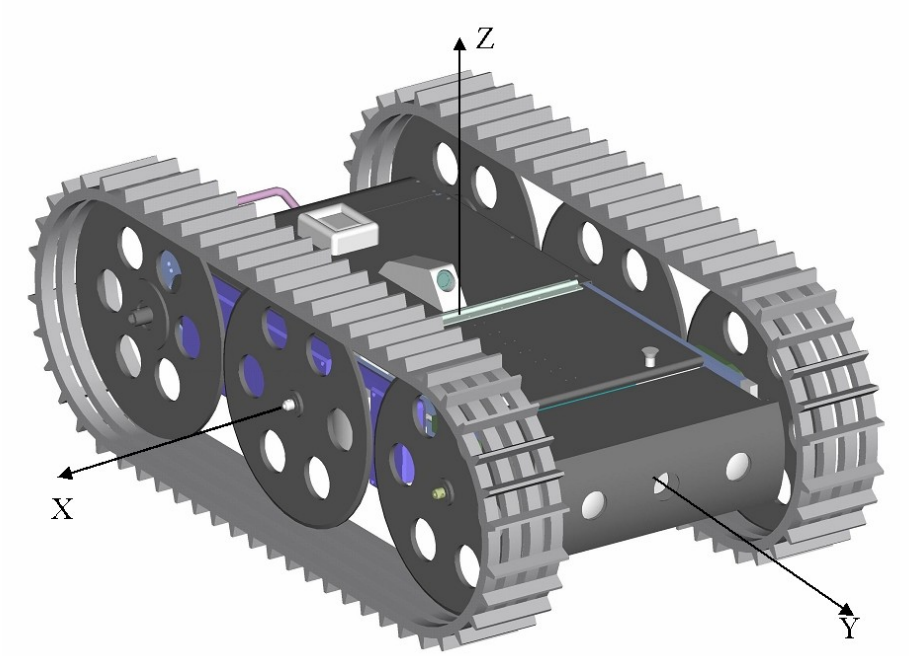
- Combines the best of the sensors to provide an optimal estimate of the vehicle state
- Helps address the high-frequency GPS noise
- GPS has a good average position and the gyro has low noise

Kalman Filter



Kalman Filter

- Filter States
  - X position
  - Y position
  - Velocity
  - Heading
  - Pitch
  - Roll
  - Turn rate



- Assumptions
  - Vehicle translates in Y directio
  - Vehicle rotates about Z axis on
  - Low dynamics

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Kalman Filter

- Measurements
  - X position → GPS
  - Y position → GPS
  - Heading → GPS
  - Velocity → GPS
  - Heading → Compass
  - Pitch → Compass
  - Roll → Compass
  - Velocity → Hall-effect sensors
  - Turn rate → Gyro

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Kalman Filter

- State transition matrix

$$F = \begin{bmatrix} 1 & 0 & -\sin\psi\cos\theta dt & 0 & 0 & 0 & 0 \\ 0 & 1 & \cos\psi\cos\theta dt & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & \sin\theta dt \\ 0 & 0 & 0 & 0 & 1 & 0 & -\tan\theta\cos\phi dt \\ 0 & 0 & 0 & 0 & 0 & 1 & (\cos\phi dt / \cos\theta) \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

where

$$x_{k+1} = F_k x_k$$

is just the dead reckoning equations in matrix form

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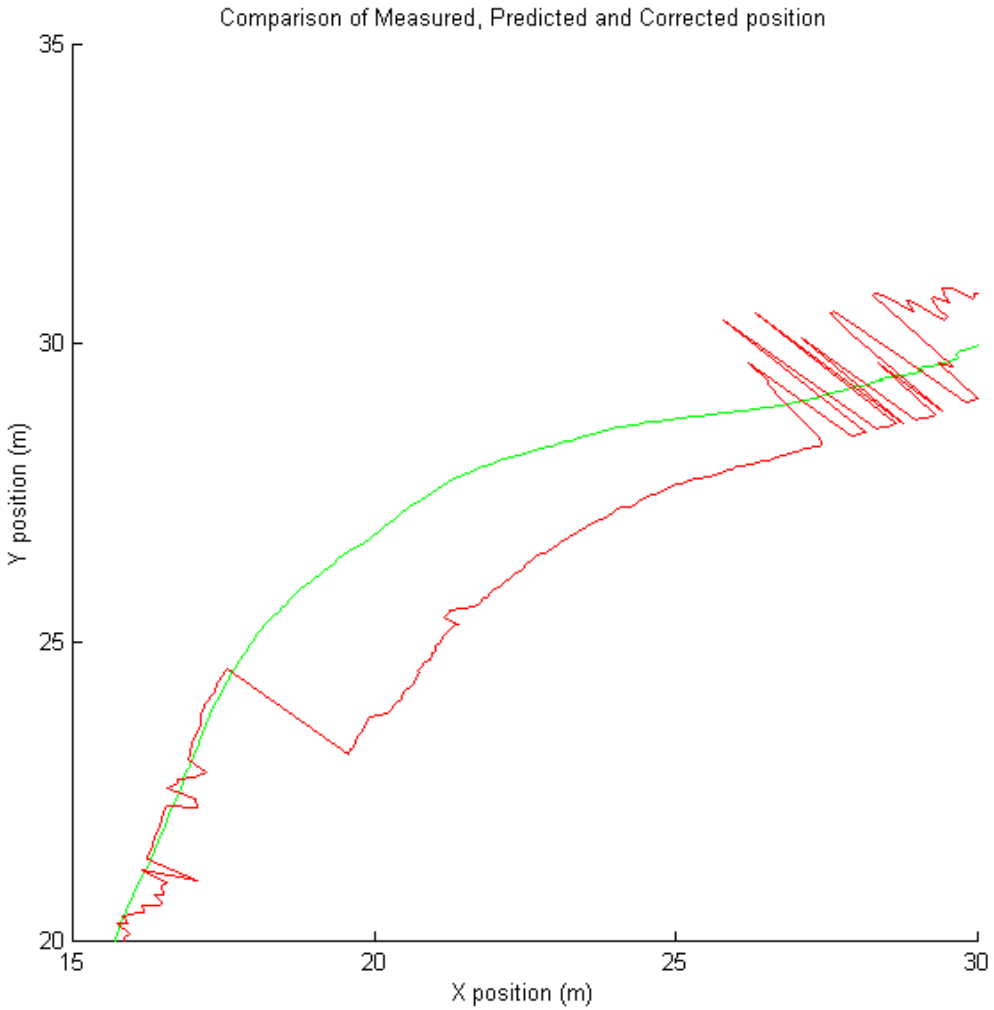
Kalman Filter

- Dynamic variation of R
  - The R matrix dictates how much each measurement is believed
  - The GPS errors that fall in between noise and drift dealt with by varying the elements in R that relate to the GPS X and Y position
  - By increasing those elements the filter puts less faith in the GPS measurements after a large jump
  - The filter's certainty is gradually increased over time if the GPS position doesn't jump back

Kalman Filter
Dynamic Variation of R



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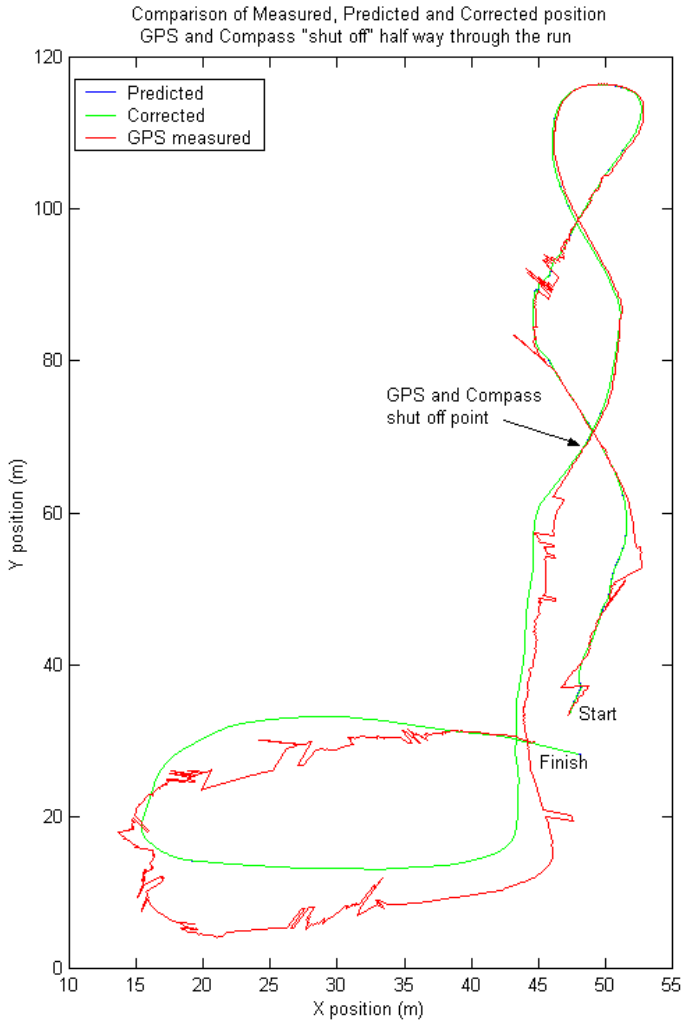
Kalman Filter

- Allows for absenc of GPS for short periods of time



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Position Update Message

- Developed to address the long-term GPS error
- Not an option to use differential GPS
- Need a higher degree of accuracy than is available from the uncorrected GPS

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Position Update Message

- Use landmarks in the terrain that can be correlated to a known position
- Terrain recognition done by the human supervisor using the real-time video feed and an aerial photo of the area
- Robot is told where it really is
- It then applies that offset to all subsequent GPS measurements

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Path Following

- The Kalman Filter only provides state information
- Path Following and PID algorithms are still required
  - A *pure pursuit* algorithm was implemented
  - The algorithm basically uses a PID loop fed by the heading error

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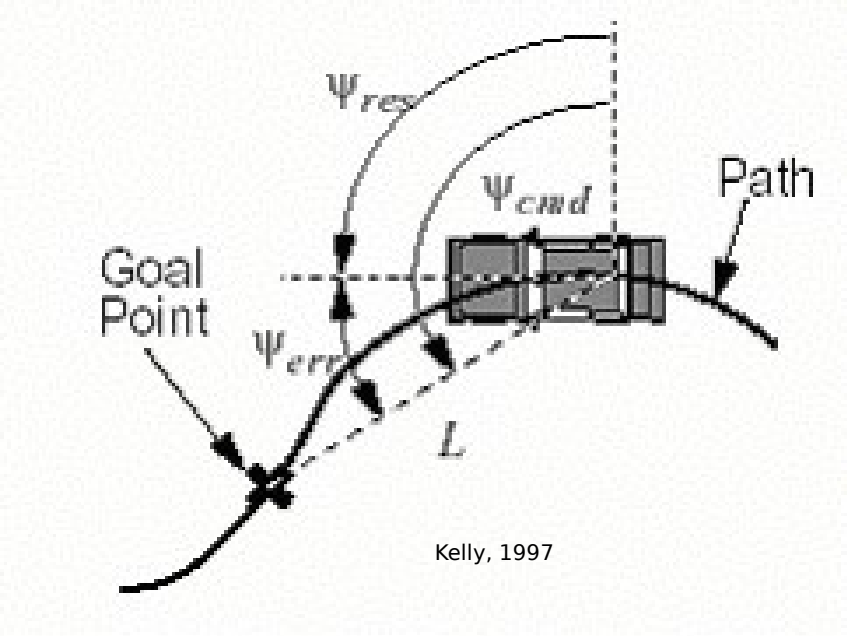
Path Following



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Operator Control Unit

- Graphical waypoint selection
- Currently uses ortho-rectified photos (1/2 foot resolution). Implementing other types now.
- Can teleoperate the robot
- Optimizes and sends paths to the robot
- Monitors vehicle status
- Displays real-time video
- MDARS MRHA compliant (controls all of our robots)
- Controls multiple vehicles simultaneously

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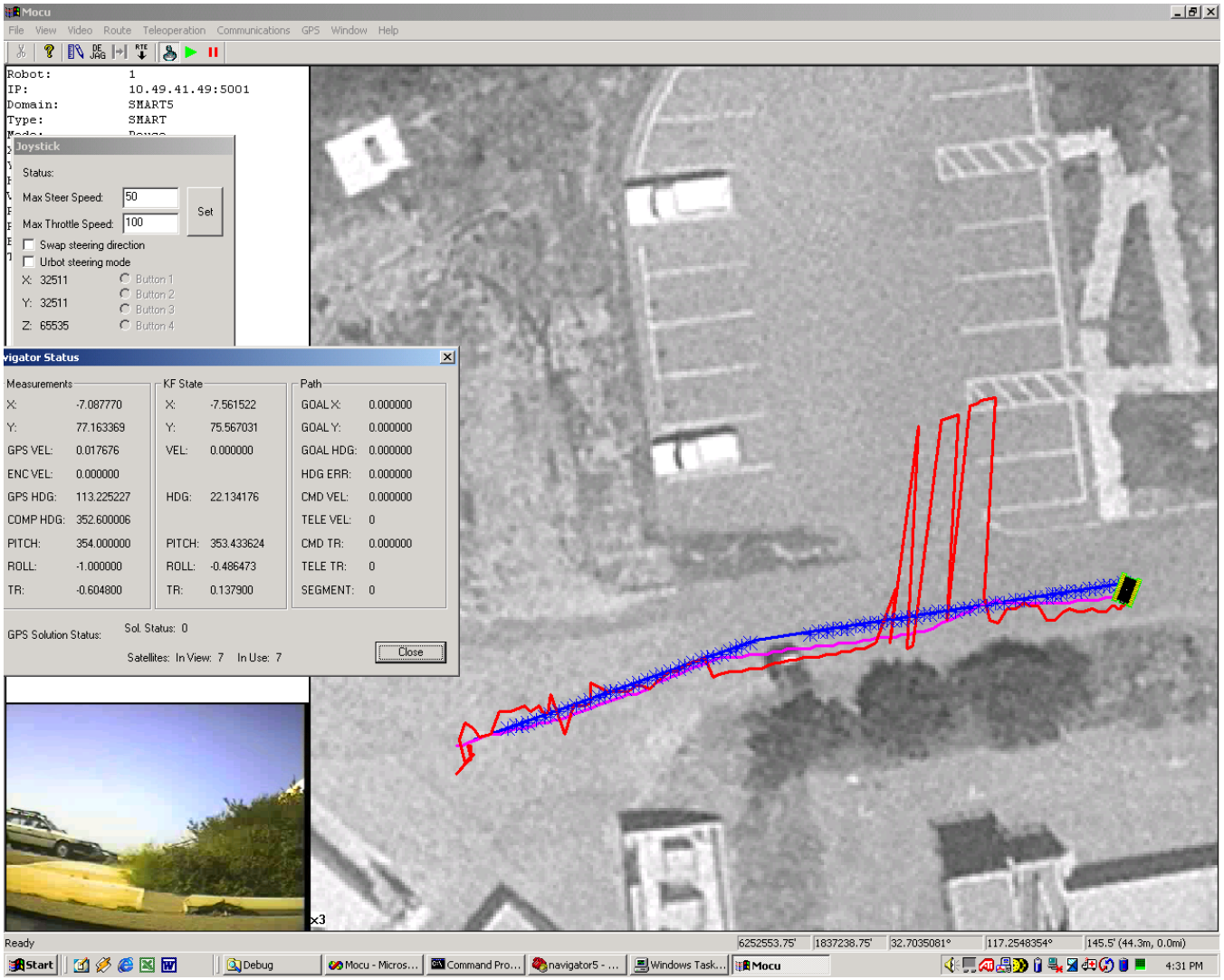
Operator Control Unit



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Summary

- Demonstrated the ability to provide an effective waypoint navigation capability to small low-cost systems such as the MPRS URBOT
  - Not computationally intensive
- Demonstrated that by separating the GPS error sources into two categories it's possible to attain accurate navigation results without the aid of differential GPS corrections

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Thank you

- This work was funded by the Unmanned Ground Vehicle/Systems Joint Program Office (UGV/S JPO)